CHAPTER 14. COLD-MIX ASPHALT RECYCLING (MATERIAL AND MIX DESIGN)

INTRODUCTION

The main purpose of recycling is to reuse existing pavement material for rehabilitation of pavements. The most important advantages of recycling are conservation of resources and money. Cold-mix recycling is one of the various recycling methods available today. Cold-mix recycling can result in a stable pavement at a total expenditure of 40 to 50 percent less than that required by conventional construction methods.[1] However, like conventional hot mix asphalt, cold-mix asphalt used for recycling must be designed properly to ensure reliable performance. The unique features of cold recycled mixes are time temperature effects (curing) due to the presence of the water and/or volatiles and the slower binder softening rate.[2] Hence, proper considerations should be given to changes in mixture properties with time and target reduction of aged binder consistency in the mix design.[3]

A standard national method for designing cold recycled mixes is not available. However, certain basic steps, as shown in the flow chart in figure 14-1,[4] are included in most mix design procedures used by highway agencies. The first step in mix design is material evaluation. The material evaluation step includes field sampling, determination of aged mix composition, and properties of aged asphalt binder and aggregates. One of the important purposes for this step is to identify the deficiencies of the aged mix and determine the need for virgin material(s). The mix design procedure consists of selection of the recycling agent and the determination of the optimum binder content. These steps are discussed in the following paragraphs.

MATERIAL EVALUATION

The material evaluation phase basically consists of sampling and testing of materials. Material from the existing pavement must be sampled in a systematic way to obtain representative samples. The important properties of the reclaimed asphalt pavement (RAP), which could affect performance of the recycled mix should be determined to ensure proper selection of new asphalt binder and virgin aggregates, if required.

Field Sampling

To obtain representative samples from each of the different sections of the existing pavement, sections of pavements with differences in pavement cross section and material composition should be delineated and treated as different units. A visual inspection and a review of construction and maintenance records can be used for this purpose. The locations for sampling from each of the unit should then be determined by the random sampling technique.[4]

At least five or six locations for sampling have been suggested by some researchers,[5] whereas others[4] suggest a minimum of five samples per kilometer or one per block in city work. One sample per lane mile for larger jobs (length greater than 6.4 km, 4 mile) with a minimum of six per project has been recommenced.[6] Generally, core samples are obtained. The thickness of

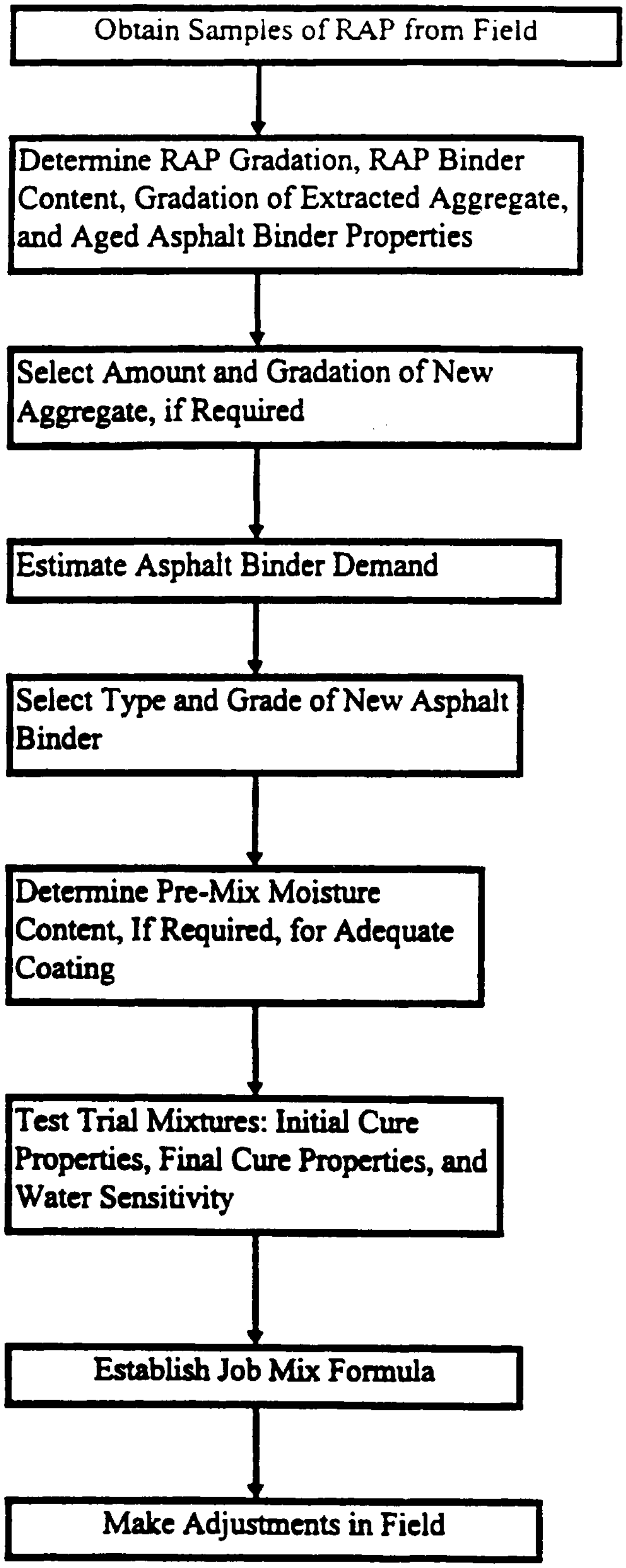

Figure 14-1. Flow chart for mix design of cold recycled mixes.

all layers in the cores should be recorded. Since the process of milling can produce more fines than the process of coring and also gives realistic samples, it is desirable to obtain field samples by the equipment proposed to be used to remove and size the reclaimed material. In this way a more representative sampling can be obtained.(2) However, this is not always possible since the use of full lane milling can generate a substantial amount of milling. This requires a substantial amount of patching material also. Hence, sampling by core or a small milling machine (30 to 45.7 cm, 12-18 in) is normally used. Quite often, cores are obtained, which are sawed-off at the desired depth of cold recycling and crushed in a laboratory jaw crusher to produce RAP for evaluation and mix design. In some states, cone penetration test is conducted at the bottom of core hole to determine the strength of the subgrade. If the subgrade is found to be weak and unstable, cold recycling may not be performed. In such a situation it is very difficult to operate the cold milling machine, which can cut through the subgrade and get stuck. Again, the importance of obtaining realistic field samples by milling cannot be overemphasized.

RAP Mix Composition

The milled RAP material must be subjected to sieve analysis using AASHTO T 27 Sieve Analysis of Fine and Coarse Aggregates. Generally, the RAP particles are treated like "black rock" or aggregates in cold-recycled mix design. AASHTO T 164-93, Quantitative Extraction of Bitumen From Bituminous Paving Mixtures, is used to determine the asphalt binder content of the RAP. For mixes that were originally made from cutback asphalts or emulsified asphalts containing solvents, a determination of "residual asphalt" can be obtained, if required, by heating the samples before extraction for about 3 hours at 120°C (248°F).(4) The aggregate extracted by AASHTO T 164-93 is subjected to sieve analysis to determine its gradation using AASHTO T 27-93, Sieve Analysis of Extracted Aggregate. The National Center for Asphalt Technology (NCAT)'s ignition test method (AASHTO TP 53-95) can also be used to determine RAP's binder content and gradation if the aged asphalt binder is not recovered for further testing, and the RAP does not contain cutback asphalt.

Properties of Aged Asphalt Binder

Aged asphalt binder should be recovered from the RAP using AASHTO T 170, Recovery of Asphalt from Solution Using Abson Method. However, the recently developed Rotovap procedure (AASHTO TP 2-94) of asphalt binder recovery (recommended by SHRP) is preferred to Abson Recovery. The recovered asphalt binder should be tested at least for penetration at 25°C (77ºF) (AASHTO T 49), and absolute viscosity at 60°C (140°F) (AASHTO T 202). The evaluation of these consistency test data is helpful in selecting a proper recycling agent for cold recycled mixes. It is anticipated that Superpave binder test properties such as $G^*/\sin\delta$ (rutting factor) will be measured in the future.

New Aggregate

New aggregates may be required to satisfy the gradation requirement or structural improvement of the recycled mix.(7) Gradation of the RAP (as received from milling or crushed from cores) may not meet the specification requirements for the intended recycled course such as base course and binder course. The RAP gradation is affected by the fines generated due to milling and pulverization, or contamination from the underlying layers or due to degradation by traffic. In some cases, RAP may consist of sand-asphalt mix. In such cases, the recycled mix gradation can be made coarse by adding new aggregate.

Additional aggregate may also be needed to increase the structural capacity of the pavement by increasing its thickness. This may be required by increased traffic loading. New aggregate may also be needed to improve recycled mix properties such as stability, durability, or workability.

The gradation of the selected new aggregates should be determined by sieve analysis AASHTO T 27-93). The new aggregate and the RAP material must be combined in proportions to meet the specified gradation.

MIX DESIGN PROCEDURES

Although no universally accepted mix design procedure for cold-mix recycling is available at present, guidelines have been developed by several agencies, based on laboratory tests, empirical formulas or past experience with identical projects. The following is a general discussion of various steps involved in cold-recycled mix design. This will be followed by specific mix design procedures used by some highway agencies.

Selection of Recycling Agent

The types of recycling agents used include emulsified recycling agents, softer grade of asphalt cements (such as grades AC-2.5, and AC-5 asphalt cement), and cutback asphalts.(2) The relevant specifications for asphalt cement for cold-mix recycling are AASHTO M226 (ASTM D 3381), and AASHTO M20 (ASTM D 946). The most commonly used recycling agent for completely cold recycling processes are emulsified asphalt cements (AASHTO T 59-93) or emulsified recycling agents (ASTM D 5505). This is because the emulsions are liquid at ambient temperatures, have the capacity for being dispersed throughout the mix, and does not cause major air pollution problems.(2) Cement, fly ash, lime or other chemical stabilizers have been used in combination with asphalt emulsions. Softer grades of asphalt cement and cutback asphalts are used very rarely. Foamed asphalt cements have been used and are more effective in terms of dispersion than asphalt cements.

The choice of recycling agent depends on the time and temperature dependent interaction between the recycling agent and the aged asphalt. At ambient temperature, the softening effect of the recycling agent is a time and temperature dependent physico-chemical process.(2) The rate at which the reaction between the recycling agent and the aged asphalt occurs is a function of the properties of the recycling agent and the aged asphalt cement, and the mechanical effects of the physical processes such as mixing, compaction, traffic and climatic conditions. When using viscosity or penetration based nomograph for determining the amount of asphalt binder needed to achieve target viscosity, consideration should be give to the fact that the reaction between the recycling agent and the asphalt cement does not take place throughout the mix at the same time, but rather starts at the interface of the recycling agent and the aged asphalt cement media. Another important consideration is that the properties of the mix, such as stability, change with the loss in moisture or volatile content. Hence, it is more important to determine the mechanical properties of the recycled mix with the emulsion before and after curing than to simply determine the consistency of the blend.(8)

The selection of recycling agent primarily depends on the asphalt demand and the reduction in viscosity of the aged asphalt cement. The relative contributions of the recycling agent and the aged asphalt binder are not fully understood at this time. One theory is that, instead of acting as an binder, the aged asphalt may largely act as part of the aggregate. In such a case there will be an effective asphalt content, consisting part of the aged asphalt and the new asphalt binder or recycling agent. This effective asphalt content will then govern the ultimate performance of the mix, rather than the total asphalt content.[9] Therefore, the testing of recycled mix for mechanical properties appears a better approach for selecting the type and amount of recycling agent.

Field coating test, as given in AASHTO T 59 (Standard Methods of Testing Emulsified Asphalts) has also been suggested for determining whether anionic or cationic emulsified asphalt is more compatible with the RAP and new aggregate. It has been recommended[4] that for determining the type and amount of recycling agent, first consideration should be given to the type and grade performing satisfactorily on local projects with aggregate gradations and traffic conditions similar to those on the project under study. Proper judgement should be used in selecting the type and grade of the recycling agent, and the decision should consider the usage of the completed pavement, environmental conditions at the pavement location, type of equipment available, and construction operations. The major consideration should be the properties of the new asphalt binder including its consistency, and curing or setting rate.

Asphalt Cements

The viscosity of various asphalts cements at the ambient temperature should be considered to ensure workability of the recycled mix. A higher viscosity can be used if the recycled mix contains a relatively low percentage of material passing the 75 µm (No. 200) sieve, but if the mix contains a high proportion of fines, it is better to use an asphalt cement of low to medium viscosity (such as AC-2.5) to ensure effective mixing. As mentioned earlier, asphalt cements are rarely used in cold recycling because of inadequate coating problems. Foamed asphalt cements have been used successfully.

Emulsified Asphalts

Laboratory evaluation of the RAP (plus aggregate if used) and emulsified asphalt is the best way to determine its suitability as a recycling agent. Different types and quantities of emulsified asphalt should be tried with the RAP to find the best combination for the intended use. The type and grade of the emulsified asphalt is selected after the material gradation (RAP + new aggregate) is determined. A guideline for choosing type and grade of emulsified asphalt is shown in table 14-1.[4] The medium-setting (MS) emulsions are designed for mixing with open- or coarse-graded aggregate. Mixes using these emulsions remain workable for an extended period of time since these grades do not break immediately upon contact with aggregate. High float medium-setting asphalt emulsions may give better aggregate coating and asphalt retention under extreme temperature conditions. They may be used with coarse- or dense-graded aggregates.

The slow-setting (SS) emulsions are designed for maximum mixing stability. They are used with dense-graded aggregate or aggregate with high fines content. All slow-setting grades have low viscosities that can be further reduced by adding water.

Table 14-1. Guideline for choosing emulsified asphalt.[4]

Type of Cold-Mix Recycling	Gradings (See Table 14-2)	AASHTO M140 ASTM D 977 (Anionic)					AASHTO M208 ASTM D 2397 (Cationic)			
		MS-2, HFMS-2	MS-2h, HFMS-2h	HFMS-2s	SS-1	SS-1h	CMS-2	CMS-2h	CSS-1	CSS-1h
Plant Mix:										
Open-graded aggregate	A,B,C	X	X				X	X		
Dense-graded aggregate	D			X	X	X			X	X
Sand	E,F			X	X	X			X	X
Mixed-in-place:										
Open-graded aggregate	A,B,C	X	X				X	X		
Dense-graded aggregate	D			X	X	X			X	X
Sand	E,F			X	X	X			X	X
Sandy soil	G			X	X	X			X	X

Note:

Only standard grades of emulsified asphalt have been listed. For certain aggregate or climatic conditions other types might be appropriate. In such cases the emulsion supplier should be consulted.

It has been suggested that a medium-setting emulsion with solvent (cationic or anionic) should be used if the penetration of the recovered asphalt binder in the RAP is less than 30, while a slow-setting emulsion should be used if the penetration of the recovered asphalt binder is greater than 30. Similarly, some agencies (such as Pennsylvania DOT) use hard residue emulsified asphalts (such as CMS-2h, HFMS-2h, and CSS-1h) when the recovered asphalt binder is soft (penetration more than 30).

Proprietary emulsified recycling agents, which are derived from the hot mix recycling agents, may be more effective in softening aged asphalt if adequately dispersed and mixed, since they contain recycling agents binders specifically designed to restore aged asphalt binders to their original properties.[2] A low quantity of recycling agent can be used to soften the aged binder without increasing the binder content, if 100 percent RAP is used. However, it may be very difficult to disperse the recycling agent if too small a quantity is used. Depending upon the amount and characteristics of the RAP in the recycled mix, a combination of recycling agent and emulsified asphalt can also be used.[2]

Some agencies (such as New Mexico State Highway Department) have used high float, polymer-modified emulsified asphalts to reduce thermal cracking, resist rutting, and provide improved early strength.

Table 14-2. Gradation guidelines for cold-mix recycling for combination of aggregate from RAP and virgin aggregate.[4]

Sieve Size	Percent Passing by Weight						
	Open-Graded			Dense-Graded			
	A	B	C	D	E	F	G
38.1 mm (1½ in.)	100			100			
25.0 mm (1 in.)	95-100	100		80-100			
19.0 mm (¾ in.)		90-100					
12.5 mm (½ in.)	25-60		100		100	100	100
9.5 mm (⅜ in.)		20-55	85-100				
4.75 mm (No. 4)	0-10	0-10		25-85	75-100	75-	75-100
2.36 mm (No. 8)	0-5	0-5				100	
1.18 mm (No. 16)			0-5				
300 µm (No. 50)							
150 µm (No. 100)						15-	15-65
75 µm (No. 200)	0-2	0-2	0-2	3-15	0-12	30	12-20
						5-12	

The ideal recycling agent should possess the following characteristics: (a) facilitate good mixing and coating, (b) should be free of solvent so that atmospheric curing is not needed, and (c) should set fast so that the roadway can be opened to traffic soon.

In the cold-mix recycling process, water may be required to facilitate coating and compaction. The water may be present as natural moisture in the RAP or aggregate, or may be added before addition of the recycling agent, or as a component of the recycling agent (such as diluted slow-setting emulsified asphalt). For mixing with an asphalt cement, it is essential that the moisture content of the material to be recycled should be 4-6 percent to cause the hot asphalt cement to foam and thereby serve as an aid to coating.[4] For asphalt emulsion, the compatibility of water with the emulsion should be checked, since water from all sources may not be compatible to the emulsion. If any adverse effect (such as premature breaking) on the emulsified asphalt is noted, a new source of water should be found. Generally, the slow-setting emulsified asphalts and the anionic grades of medium setting emulsified asphalts require moisture for mixing.[4] The HFMS grades (particularly the HFMS-2s) and the CMS-2 and 2h emulsions, along with other available modifications, contain a quantity of petroleum distillates. These products perform much better with dry aggregates (mixing, laying, etc), than with wet aggregates.[4]

In any case, it is recommended to perform a coating test in the laboratory to determine if premix moisture content is needed to disperse the selected emulsified asphalt and if so, the amount of moisture content needed.

Asphalt Demand of the Recycled Mix

The amount of new inder required for cold in-place recycling generally ranges from 0.5 to 3 percent for emulsified asphalts. This is equated to 0.3 to 2 percent residual asphalt cement for emulsified asphalts. Most highway agencies prepare trial recycled mixtures containing 1, 1.5, 2, 2.5, and 3 percent emulsified asphalt. Higher amounts are needed if new aggregate is incorporated in the RAP.

Very few agencies use empirical formulas, such as suggested by the Asphalt Institute,[4] to estimate the total asphalt demand of the recycled mix based on the surface area of the extracted gradation of the RAP or the RAP/aggregate blend. Such formulas have not been thoroughly validated in the field and, therefore, are not given here.

For in-place cold recycling construction it is often better to proportion asphalt binder based on the weight of the aggregate. This conversion is as follows:

Percent of new asphalt by weight of aggregate, $P_d = \dfrac{100\boldsymbol{P_r}}{100 - \boldsymbol{P_r}}$

where:

P_r = Percent of new asphalt in the recycled mix

Some agencies[10] use an optimum liquid content (consisting of emulsion content and water) of 4.5 percent in all trial mixtures. For example, water contents of 4.0 percent, 3.5 percent, 3.0 percent and 2.5 percent would be used with emulsion contents of 0.5 percent, 1.0 percent, 1.5 percent, and 2.0 percent, respectively.

As mentioned earlier, there is no standard national procedure for designing cold-recycled asphalt mixtures. However, some agencies and groups appear to have the most developed mix design procedures.[10] Methods proposed by the Asphalt Recycling and Reclaiming Association (ARRA), California, Chevron, Oregon, Pennsylvania, and the Asphalt Institute are reviewed below.

Asphalt Recycling and Reclaiming Association (ARRA)[11]

The ARRA guidelines indicate three different methods for cold-mix asphalt mix design. Two of these methods consist of modified Marshall and Hveem methods intended for designing cold recycled mixtures with asphalt emulsion or emulsified recycling agent (ERA). The third procedure has been developed by Oregon State University for determination of required asphalt emulsion content. These three methods are discussed briefly in the following paragraphs.

1. **Modified Marshall, Method A.** The design mixtures are prepared in such a way so as to achieve a 3 percent total water content (percent emulsion water + percent water remaining in RAP + percent mixture water added). Emulsions are incorporated into the mixtures at desired content in 0.5 percent increments. Mixtures are then compacted with 50 blow (per face) of the Marshall compacting hammer. The compacted specimens are cured for 6 hours at 60°C (140°F). Next, the specimens are tested for bulk specific gravity, stability (60°C), and flow (60°C). The maximum specific gravity is then determined. Finally, at the optimum additive content, specimens are prepared at additional total water content at 0.5 percent increment (such as 2.0

percent, 2.5 percent, 3.5 percent and 4.0 percent). The average void content for each moisture content is then determined. The recommended mix design parameters include minimum and maximum design air voids of 9 and 14 percent, respectively.

2. **Modified Hveem, Method B.** In this method, the method of specimen preparation is same as in Method A. However, instead of using the Marshall compactor, specimens are compacted with the kneading compactor. Approximately 20 tamping blows are applied at 1.725 MPa (250 psi) pressure to accomplish a semi-compacted condition. Next, the compaction pressure is raised to 3.45 MPa and 150 tamping blows are applied to complete the compaction. The specimen is then subjected to a leveling-off load with a testing machine at 5.6 KN (1250 lbf) at a head speed of 1 mm (0.05 in) per minute. Next, the specimens are tested for bulk specific gravity and stabilometer value (60°C). The maximum specific gravity is determined at one additive content. Finally, at the optimum additive content, specimens are prepared at additional varying total water contents, such as 2.0 percent, 2.5 percent, 3.5 percent and 4 percent. Void content of these specimens are then determined.

   The recommended mix design parameters include minimum and maximum design air voids of 9 and 14 percent, respectively.

   For both Method A and B, ARRA recommends (optional) the use of mix testing for moisture sensitivity or susceptibility in accordance with AASHTO T 283, "Resistance of Compacted Bituminous Mixture to Moisture Induced Damage."

3. **Oregon Estimation, Method C.** This method has been used in Oregon for selecting an initial asphalt emulsion content to be added to the recycled mix containing 100 percent RAP and no new aggregate. The procedure consists of adjusting a base emulsion content of 1.2 percent (by weight of RAP) on the basis of properties of aggregate and asphalt binder recovered from RAP. The method is applicable only when a cationic medium setting or anionic high float medium setting type (HFE-150) emulsion is used as a recycling agent. First the gradation of RAP millings are determined for the 12.5-mm (½-in), 6.3-mm (¼-in), and 2.0-mm (No. 10) sieves. The asphalt binder recovered from the RAP is then tested for penetration at 25°C and absolute viscosity at 60°C. The estimated asphalt emulsion content is then determined from the following equation and figure 14-2.

$$EC_{EST} = 1.2 + A_G + A_{AC} + A_{P/V}$$

   where:

   EC_{EST} = Estimated added emulsion content, percent
   1.2 = Base emulsion content, percent
   A_G = Adjustment for milling gradations, percent.
   A_{AC} = Adjustment for milling residual asphalt content, percent
   $A_{P/V}$ = Adjustment for millings penetration or viscosity, percent

In this method, for the cases falling on a boundary, the adjustments resulting in a lower estimated

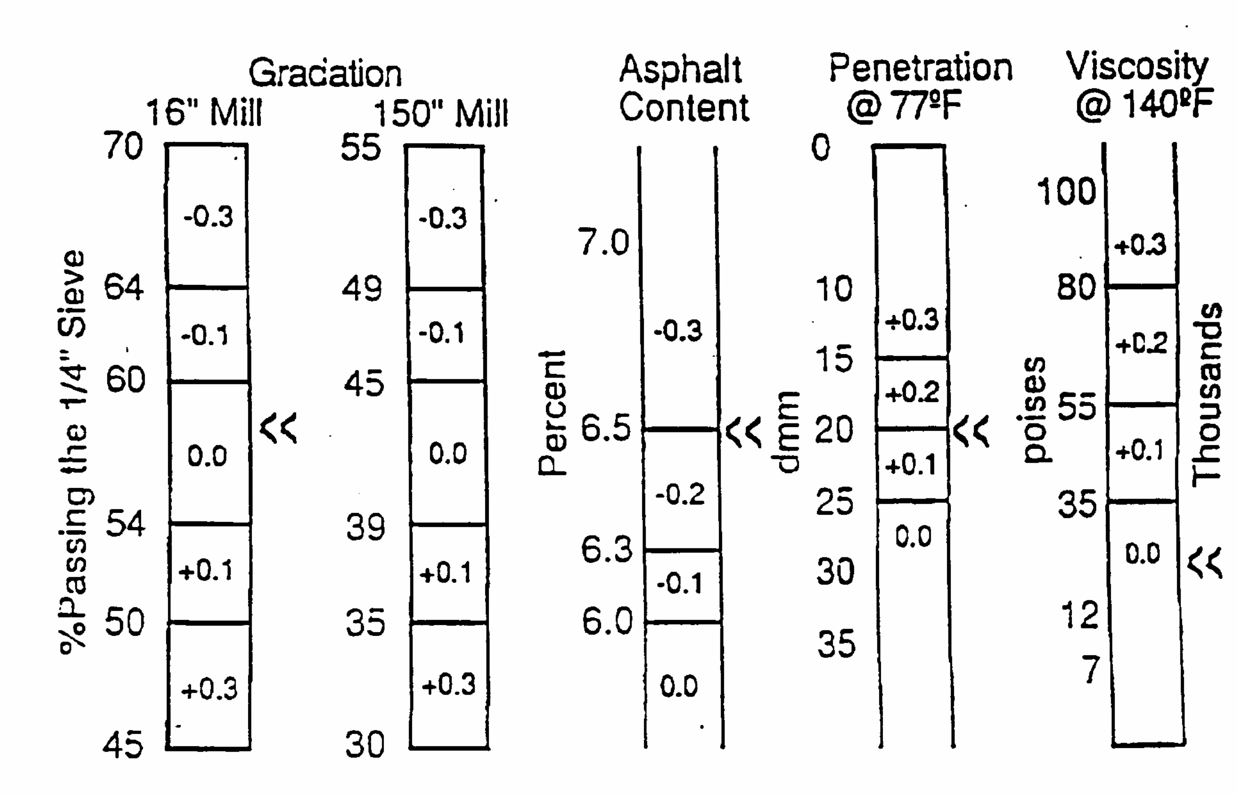

Figure 14-2. Emulsion content adjustment for determining EC_{EST} (ARRA/Oregon method).

emulsion content (EC_{EST}) should be used. If a discrepancy exists between the adjustments for penetration and absolute viscosity, the adjustments resulting in a low EC_{EST} should be used. Next, the percent of water needed is established by determining the required total liquid content. Sample of pavement RAP are prepared at estimated emulsion content with incremental water contents, such as 1.0, 1.5, and 2.0 percent. The weight of each of the samples is recorded. Next, the samples are placed and rodded in a 101.6-mm (4-in) (diameter) x 292.1-mm (11.5-in) (height) split mold in two lifts. Each of the samples is then gradually compressed in a hydraulic compaction device to a load of 172,400 kPa (25,000 psi)—one minute to achieve 137, 900 kPa (20,000 psi) plus one half minute to obtain the additional 34,500 kPa (5,000 psi). The 172,400 kPa (25,000 psi) load should be held for one minute. After compression, the specimen weights are determined, and the difference between the initial and compacted sample weight is recorded as the total liquid loss. The design total liquid content should be the total liquid content that results in a liquid loss of 1 to 4 grams. The amount of water needed is then determined by subtracting the estimated emulsion content and the existing water content of the RAP from the design total liquid content.

California Mix Design Method[10]

The California mix design guidelines specify method of sample preparation from pavement cores, gradation of material obtained by crushing of RAP, and sample preparation method for pulverized field samples. Pulverized field samples are to be checked for gradation using 38-mm (1½-in), 25-

mm (1-in), 20-mm (¾-in), 9.5-mm (⅜-in) and 4.75-mm (4-in) sieves. The specifications also require determination of viscosity of aged asphalt obtained by extraction from RAP. A method of determination of amount and grade of recycling agent is given, and curing of laboratory samples are indicated. The mix design tests specified include bulk specific gravity, air voids, and stability (with stabilometer) of the compacted recycled mix. The selected emulsion content is the highest emulsion content that provides a specimen with the desired stabilometer value, no evidence of surface flushing or bleeding, and a minimum of 4 percent voids.

Chevron Mix Design Method[10]

The Chevron mix design method for cold-mix recycling consists of the following six steps:

1. Evaluation of RAP.
2. Selection of amount and gradation of untreated aggregate.
3. Estimation of asphalt binder demand.
4. Selection of type and amount of emulsified recycling agent.
5. Testing of trial mixes.
6. Determination of job mix formula.

Methods to determine asphalt content, consistency of asphalt binder in RAP and gradation of extracted aggregate are discussed. Procedures for determination of virgin aggregate gradation and amount, and estimation of asphalt binder demand are specified. A guide for selection of type and amount of emulsified recycling agent is presented. Trial mixes, at both early cure and fully cured condition are tested for resilient modulus, stabilometer and cohesiometer values. The final job mix formula is selected based on the lowest emulsifying recycling agent content (minimum of 2 percent) that meets the design criteria for resilient modulus, stabilometer and cohesiometer values. The use of 100 percent RAP is allowed in this method. Detailed design examples are provided in this method.

Oregon Mix Design Method[10]

In this method, the steps for preparation of samples and estimation of emulsion and water content are the same as indicated in the ARRA method (Method 3 - Oregon Estimation). However, there is an additional step in which the emulsion contents producing the peak Hveem stability and resilient modulus are to be evaluated.

Pennsylvania Mix Design Method[10]

The Pennsylvania mix design method specifies RAP sample size, and procedures for determination of optimum moisture and emulsion contents. The initial evaluation consists of determination of gradation of aggregate in the RAP, asphalt content of the RAP, and penetration and viscosity of asphalt binder extracted from the RAP material.

Two series of tests are conducted in this method. A set of coating tests are run on specimens with different moisture content but constant emulsion content. Based on the results, an optimum moisture content is determined. Next, the optimum emulsion content is determined on the basis of water-conditioned and unconditioned resilient modulus tests on cured, compacted specimens.

Asphalt Institute Mix Design Method[10]

The Asphalt Institute mix design method consists of the following steps:

1. Determination of combined aggregate gradation (for virgin and RAP aggregates). The prerequisite to this step is determination of gradation of aggregate and asphalt content of the RAP material.
2. Selection of grade of new asphalt binder.
3. Determination of percent asphalt demand of the combined aggregate on the basis of suggested empirical formula.
4. Calculation of percent of new asphalt in the mix.
5. Field mix trial for adjusting asphalt content.

Detailed design examples are provided in this method.

SUMMARY

With its unique potential of conserving resource and energy, cold-mix recycling has become one of the most popular rehabilitation technique. To ensure proper performance, the design of cold-mix should be based on considerations of time and temperature effects on the recycled mix and slower binder softening rate. The first step is proper material evaluation by representative sampling and testing. The composition (asphalt content and gradation) of the reclaimed asphalt pavement (RAP) or milled material must be determined. The viscosity and penetration properties of the recovered asphalt cement from the RAP are also determined. The amount of new aggregates needed, if any, is determined on the basis of the target gradation of the recycled mix and the gradation of the RAP or milled material. Guidelines are available for selecting a proper recycling agent which is generally an emulsified asphalt. Laboratory tests (such as coating tests) must be carried out to ensure the compatibility of the recycling agent and the RAP/new aggregate mixture. The selection of the recycling agent primarily depends upon the gradation of RAP (plus new aggregate, if needed) and the consistency of the aged asphalt binder in the RAP. Proper judgement, along with knowledge about type and grade of recycling agents which have performed satisfactorily on similar local projects, are helpful. Finally, the amount of emulsified asphalt and water (if needed for dispersing the recycling agent) is determined by preparing and testing several trial mixes containing varying amounts of these components. Although no national standard test method is available for designing cold-recycled mixes, several agencies and groups have fully developed their own mix design procedures which have been presented.

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